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A STUDY OF ALGAL ESTABLISHMENT AND GROWTH IN ACID MINE DRAINAGE (AMD) SEEPS AND PRECIPITATION PONDS

FINAL REPORT

BY: M. Kalin and W.N. Wheeler

Work on this project was conducted under the auspices of the Canada Centre for Mining and Energy Technology, Energy, Mines, and Resources Canada

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EXECUTIVE SUMMARY

Algae can frequently be found in acid mine drainage seeps. Their distribution in the waste water stream, however, is patchy. If present in high densities, and in the entire waste stream, algae could be utilized as polishing agents. In order to develop biological polishing systems, it is necessary to understand the factors controlling algal distributions.

An acidic seep from an inactive coal dump in Nova Scotia was used to determine those factors which control presence or absence of algae in waste water. At this site, algal populations (primarily *Ulothrix* and *Temnogametum*) exist only in the immediate vicinity of the point of emergence of the seep, being absent further downstream.

A diffuse seepage from a seepage collection pond harbours abundant algal populations of a similar composition with no distribution boundaries. By comparing and contrasting the physical and chemical conditions in both seeps, parameters necessary for algal survival and growth in the upper ditch could be determined.

The seeps emerges from the coal dump with a pH of 4.0-4.5; acidity varies between 450 and 700 mg L^{-1} $CaCO_3$ equivalents; iron varies between 100 and 400 mg L^{-1}; sulphur between 200 and 1000 mg L^{-1}; aluminum between 25 and 100 mg L^{-1}; and phosphorus between detection limit and 1.7 mg L^{-1}. In the diffuse seepage the pH is lower, 3.4-4.0; and the acidity is higher, ranging between 800 and 900 mg L^{-1} CaCO3 equivalents. Iron concentration is 25 mg L^{-1}, sulphur 700 mg L^{-1}, aluminum 100 mg L^{-1}, and phosphorus was at or below detection limit. The chemical composition differences between the seeps are the result of the oxidation of the reduced iron, present at the point of emergence of the seep.

The algae growing in the emerging seep contained 26% iron, 6.3% sulphur, and 1% aluminum, on a dry weight basis. Calcium and magnesium reached concentrations as high as 2.5 and 1.6% of dry weight, respectively. Phosphorus was also found at levels of 0.1 to 0.4% of dry weight. In the oxidized seep the algal complexes contained only 1.7% iron, 0.4% sulphur, and 0.2% aluminum.

Transplanting experiments indicated that algae died at pHs lower than 3.3. Enclosures with sodium bicarbonate, straw, alfalfa pellets, and fertilizer were added to seepage water at pH 2.5, as amendments for algal establishment. After 2 months, algae transplanted into the enclosures were still alive.

Net photosynthetic rates of algae in the emerging seep ranged between 0.35 and 0.56 mg O_2 gdw^{-1} h^{-1}. Net photosynthetic rates in the oxidized seep were 1.44 to 3.17 mg O_2 gdw^{-1} h^{-1}, nearly 6 times faster. Algal net photosynthetic rates decreased as pH decreased. The point at which the rates fell through 0 correlated well with the distribution limit of algae in the upper seepage ditch (pH 3.3).

Factors which are relevant to algal distribution seem to be related to the oxidation process and nutrient availability. Phosphorus can be expected to be co-precipitated during iron oxidation, becoming a growth-limiting nutrient.

RÉSUMÉ

Il est fréquent de trouver des algues dans des infiltrations de drainage acide de mine. Leur distribution dans le courant d'eau résiduaire, est cependant par taches. Si elles étaient présentes en fortes densités, et dans la totalité du courant résiduaire, les algues pourraient être utilisées en tant qu'agent d'épuration. Afin de développer des systèmes d'épuration biologiques, il est nécessaire de comprendre les facteurs contrôlant la distribution des algues.

Une infiltration acide d'une décharge de charbon désaffectée en Nouvelle-Écosse, était utilisée pour déterminer ceux des facteurs qui contrôlent la présence ou l'absence d'algues dans les eaux résiduaires. Sur ce site, les populations d'algues (principalement *Ulothrix* et *Temnogametum*) existent uniquement dans le voisinage immédiat des points d'émergence de l'infiltration, étant absents plus bas en aval.

Une infiltration diffuse, provenant d'un bassin de récupération d'infiltrations, abrite des populations d'algues abondantes, de composition similaire, sans limites de distribution. Par la comparaison et la mise en opposition des conditions chimiques et physiques dans les deux infiltrations, les paramètres nécessaires à la survie et la croissance des algues dans la rigole supérieure pouvaient être déterminés.

L'infiltration émerge de la décharge de charbon avec un pH de 4,0-4,5; l'acidité varie entre 450 et 700 mg/l d'équivalents de $CaCO_3$; le fer varie entre 100 et 400 mg/l; le soufre entre 200 et 1 000 mg/l; l'aluminium entre 25 et 100 mg/l; et le phosphore entre la limite de détection et 1,7 mg/l. Dans l'infiltration diffuse, le pH est inférieur, 3,4-4,0; et l'acidité est plus élevée, allant de 800 à 900 mg/l d'équivalents de $CaCO_3$. La concentration en fer est de 25 mg/l, en soufre de 700 mg/l, en aluminium de 100 mg/l, et le phosphore se situait au niveau ou en-deçà de la limite de détection. Les différences de composition chimique entre les infiltrations sont le résultat de l'oxydation de l'ion réduit, présent au point d'émergence de l'infiltration.

Les algues poussant dans l'infiltration qui émerge, contiennent 26% de fer, 6,3% de soufre, et 1% d'aluminium, sur une base de poids sec. Le calcium et le magnésium ont atteint des concentrations aussi élevées que, respectivement, 2,5 et 1,6% de poids sec. On a trouvé également du phosphore à des niveaux de 0,1 à 0,4% de poids sec. Dans l'infiltration oxydée, les complexes d'algue contenaient seulement 1,7% de fer, 0,4% de soufre, et 0,2% d'aluminium.

Des expériences de transplantation ont indiqué que les algues mouraient à des pHs inférieurs à 3,3. Des inclusions avec du bicarbonate de soude, de la paille, des nodules de luzerne, et de l'engrais, étaient ajoutées à l'eau d'infiltration à un pH de 2,5, en tant qu'additions aux établissements d'algue. Après deux mois, les algues transplantées dans les inclusions étaient toujours en vie.

Les taux nets de photosynthèse des algues dans les infiltrations émergentes allaient de 0,35 à 0,56 $mgO_2\ gps^{-1}\ h^{-1}$. Les taux nets de photosynthèse dans l'infiltration oxydée étaient de 1,44 à 3,17 $mgO_2\ gps^{-1}\ h^{-1}$, presque six fois plus rapides. Les taux nets de photosynthèse de l'algue baissaient lorsque le pH baissait. Le point à partir duquel les taux baissaient en-dessous de 0 présentaient une bonne corrélation avec la limite de la distribution des algues dans la rigole d'infiltration supérieure (pH 3,3).

Des facteurs, qui semblent avoir un rapport avec la distribution de l'algue, semblent être liés au procédé d'oxydation et de disponibilité de nutriments. On peut s'attendre à ce que le phosphore soit co-précipité pendant l'oxydation du fer, devenant un nutriment limitant la croissance.

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1.0 INTRODUCTION

Water degradation due to acid mine drainage (AMD) from coal wastes is a significant economic and environmental liability. Treatment approaches using lime or other neutralizing agents, aim to increase pH and thereby precipitate metals. This form of treatment results in the formation of large sludge volumes and treatment may often be required in perpetuity.

Iron precipitation as ferric hydroxide occurs naturally during the oxidation of reduced iron. The precipitate coats surfaces in the acid mine drainage seeps and forms either hard coats on rocks or forms soft sludges, which accumulate around attached algae and vegetation. The formation of precipitate and its association with attached algae are important components in developing alternative methods in the remediation of acid mine drainage. These methods are referred to as biological polishing, where algae serve as collection agents for precipitate and remove metals from the acid mine drainage stream.

This work focuses on the problem of the establishment of algal populations as biological polishing agents in precipitation ponds and seeps. From the literature and based on field observations, it has been concluded that such establishment and use of periphyton in precipitation ponds are possible (Kalin et al. 1991). This report describes efforts to understand the conditions necessary for algal survival and growth in seeps and precipitation ponds.

1.1 Site Description

Selminco Summit is an old coal waste dump, located in close vicinity to the town of New Waterford on Cape Breton Island (MAP 1). AMD seeps occur along the toe of the waste rock pile. In 1989 Boojum Research was contracted to implement Ecological Engineering measures at the Selminco site. Implementation included designing a system for the treatment of AMD emerging from the waste dump. The proposed system consisted of a series of precipitation ponds, followed by 2 ponds in which ARUM (Acid Reduction Using Microbiology) would operate, reducing sulphate and acidity (MAP 2). In the ARUM ponds, organic matter is supplied as a nutrient source for microbial populations and floating cattails provide a cover over the sediment. Precipitation ponds are required to prevent coating of the organic matter with iron hydroxide precipitate.

Based on previous investigations, iron precipitation was expected to occur due to mixing of fresh water run off with AMD seepage water. However, it has not been possible, to date, even with a carefully designed system, to achieve effective iron precipitation.

Algal populations occur in the AMD seeps at the site. Algae grow at the point of emergence of the main seep (A11, MAP 2; PLATE 2), but further downstream the seepage stream is devoid of algae (PLATE 2). A detailed description of the upper seepage stream (A11) is given in MAP 3. The lower seep, running parallel to the ARUM ponds is completely covered with dense algal populations (MAP 2). The differences between the

upper and lower seeps, with respect to chemical, biological and physical characteristics are described below.

2.0 METHODS

2.1 Field Observation

Field observations at the Selminco site were carried out in early and mid June, in August, and in October 1991. Observations included pH, Eh, conductivity, water temperature, and distribution of algae in the upper seepage ditch.

Water samples were collected periodically for elemental composition, laboratory tests of acidity, and nutrient measurements. Plastic bottles (150 mL) were filled to the brim with waste water, and sealed tightly. The samples were kept cool until processed (see section 2.2).

Algal samples were collected for dry weight determinations, and elemental composition. Samples were collected in plastic Whirl Pak bags, with as little local debris and water as possible. Samples were kept cool until processed.

Field observations were made of plant nutrients, using Hach kits for orthophosphate (Model PO-19), nitrate (Model NI-14), ammonia, (Model NI-8) and chloride (Model 8-P). Ferric iron was also determined on one trip, using the ferricyanide method.

Acidity was determined on selected water samples from the site. For this, a 5 mL aliquot of test water was titrated against 0.01 N H_2SO_4 to an end point of pH 8.3. The results were multiplied by 100 to get mg L^{-1} calcium carbonate equivalents.

2.2 Water Chemistry

Collected water samples were filtered through 0.45μm membrane filters, and acidified to < pH 1 using nitric acid. The samples were kept cool, and returned to the lab. Elemental analyses were performed by Inductively Coupled Plasma Spectroscopy, at a certified laboratory.

2.3 PPC Composition

Algal material from the seepage ditches was further cleaned of debris, dried in an oven at 40-60 °C for 2 to 3 days, weighed, and powdered in a hand mortar. Elemental analysis was performed by Inductively Coupled Plasma Spectroscopy by a certified laboratory. Loss on Ignition was also performed on the samples, in a muffle furnace at 500 °C, for 30 min.

2.4 Taxonomy

Live samples were brought back to the laboratory for culturing in original seepage water and in culture medium (Hargreaves and Whitton, 1976). Identifications were carried out on subsamples of field material which had been preserved in Lugols fixative, by Mary Olaveson of Algatax, who specializes in acid mine drainage algal taxonomy.

2.5 Photosynthesis

Photosynthesis of the algal populations in seepage water was measured by the method of Dor and Levy (1987), using an oxygen electrode (YSI 54). Both light and dark bottles (1 L) contained approximately 10-20 gms fresh weight algae. Bottles were incubated submerged in the collection ditch for 1-2 hours, under sunny skies. The change in oxygen concentration in the bottles was then measured. Algal material in the bottles was stored cool in plastic bags until it could be dried, weighed, and powdered. Subsamples of the algae were analyzed for LOI, as above.

Photosynthetic rates of algae from the 18.9 m seep, were determined in water from different areas of the Selminco site. The oxygen changes in incubated scintillation vials were measured using the Winkler titration method. A 1 gram sample of algae, collected from the upper ditch seep at 18.9 m, was incubated in each of 4 scintillation vials with water from the upper ditch at seeps 18.9 m (pH 3.99) and 21 m (pH 4.17), precipitation pond #1 (pH 2.99),

and ARUM pond #1 (pH 2.97; see MAPS 2,3). After a period of 1 hour, the solutions were fixed with manganese sulphate and alkaline iodide. The titrations were performed in the laboratory.

2.6 Carbohydrates

Extracellular carbohydrates in water from the two ditches were measured using the method of Kochert (1978). One mL of waste water was added to a test tube with 1 mL of 20% phenol and 5 mL of concentrated sulphuric acid. The color development was compared by eye to freshly made glucose standards of 0.02, 0.04, 0.06, 0.08 and 0.1 g L^{-1}.

Water samples used in the carbohydrate test came from both the upper and lower seepage ditch. In the upper ditch, samples were taken at the 18.9 m seep, in the main flow. In the lower seepage ditch, at the seep 90 m below the first riffle (MAP 2).

2.7 Transplant Experiments

2.7.1 Experiment 1

In 1990, in an attempt to "seed" the precipitation ponds with algae, 20-30 large brush cuttings were strewn into the first and second sections of the first precipitation pond. This brush was to act as surface area for algal colonization and development. Shortly after, 70

kg of a mixture of *Spirogyra* and *Zygogonium* from an area to the south of the Selminco system were transplanted to the precipitation pond.

2.7.2 Peritraps - Experiment 2

In order to test the ability of algae to live in precipitation ponds under a number of different environmental conditions, small semi-enclosed environments (peritraps) were set up in the first precipitation pond (SCHEMATIC 1). Peritraps were designed to quantify periphyton growth rates at this and other mining sites by providing a quantifiable surface area above a bag in which different nutrient or amendment sources could be placed. In the enclosed volume local environmental conditions could be changed, and their affect on algal survival and growth could be determined.

The peritraps installed on June 1, 1991, contained the following additives. Trap 1 contained 130 g slow-release fertilizer (Osmocote 19:6:12) and 2 kg limestone rock. Trap 2 contained 2 kg of limestone rock. Trap 3 held hay amendment from the ARUM bog. Trap 4 was used as a control, with no amendments. Trap 5 contained 130 g slow-release fertilizer (Osmocote 19:6:12), and trap 6 held hay amendment from the ARUM bog and 1 kg slow-release fertilizer (Osmocote 19:6:12).

Besides the bag amendments, traps 1,2,3, and 5 were inoculated with about 5 grams fresh weight (gfw) algae from the A11 seep area. Trap 6 received about 1 kg of algal slurry from

the same area. The top mesh was removed from trap 6 to allow more light into the bottom of the bag. The traps were checked for survival after 2 weeks.

2.7.3 Peritraps - Experiment 3

The traps were re-inoculated with algae from the A11 seepage area. Each trap received about 5 gfw of algae, except for the control, #4. The algae were carefully placed in the bottom of the bags where the chemical environment was more amenable to growth. The second experiment lasted 23 days.

2.7.4 Peritraps - Experiment 4

Traps 5 and 6 were set up as limnocorrals on the July trip. Raising the bag opening above the surface effectively prevented the exchange of water between the bag and the bulk water. The top netting was removed, leaving just the bag. More buoyancy was placed around the frame, and longer ropes allowed the lower frame to float on the surface.

Two hundred grams of slow-release calcium phosphate (Sierra custom formulation) was placed in the bottom of limnocorral 5. Limnocorral 6 was given a 1 kg NPK slow-release fertilizer bag (Osmocote 19:6:12) and a small amount of the original hay (appx. 2 kg). The open limnocorrals were placed further out into the middle of the channel. The bags were

re-inoculated with about 100 gfw algae each from the A11 seepage ditch. Traps were checked after 40 days.

2.7.5 Peritraps - Experiment 5

During the August trip, a third limnocorral was constructed from peritrap 4. Limnocorral 4 was set up with approximately 2 kg of sodium bicarbonate, tightly wrapped in a bag, with several knife slits for water exchange. Limnocorral 5 received clean hay (e.g. no precipitates) and about 1 kg of alfalfa pellets. Limnocorral 6 continued to receive hay and NPK fertilizer. However, the initial pH of the bags was brought up above 3.5 using sodium bicarbonate. All three limnocorrals were reinoculated with approximately 50 gfw of A11 seepage algae. Limnocorrals were checked after 60 days.

3.0 RESULTS

3.1 Field Observations

Water emerges from the A11 seep with a pH of 4.0 to 4.5. Ehs of the water were positive, averaging around 200 mV (MAPS 2,3; TABLE 1). Acidity varied between 455 and 700 mg L^{-1} (calcium carbonate equivalents). Conductivities ranged between 590 and 2070 μmhos cm^{-1}.

The lower ditch seep at 90 m had a pH of 3.9, an Eh of 253 mV, and a conductivity of 2400 μmhos cm^{-1} (MAP 2; TABLE 1). Acidity of the seepage water was 910 mg L^{-1} calcium carbonate equivalents.

The upper seepage ditch had approximately 15 seeps, including the A11 seep. These seeps contribute a volume that ranges from 1000 cm^3 s^{-1} with no surface run off during dry periods to 36,000 cm^3 s^{-1} in wet periods with surface run off. The seeps in the ditch had mean pHs that averaged 4.0 in June, 3.9 in August, and 3.9 in October (TABLES 2,3,4). Conductivities of seepage water averaged 1430 μmhos cm^{-1} in June, 2700 μmhos cm^{-1} in August, and 1700 μmhos cm^{-1} in October. Average Ehs ranged from 270 mV in June, 220 mV in August, and 197 mV in October (TABLES 2,3, and 4).

Surveys of the upper seepage ditch from A11 through the precipitation cells were produced in June, August and October. The main flow of the ditch had pHs which ranged from 3.9-3.3 in June, 4.0-3.4 in August, and 3.9-3.6 in October. Ehs varied between 244 and 339 mV in June, 250 to 342 mV in August, and 284-318 mV in October. Conductivities of the main flow ranged between 1950 and 3450 μmhos cm^{-1} in June, 1750 and 4180 μmhos cm^{-1} in August, and between 1830 and 2650 μmhos cm^{-1} in October (TABLES 2,3, and 4). On the first June trip oxygen measurements were made on the seepage water. These varied from a low of 1.0 mg L^{-1} at the A11 seep, to 8 mg L^{-1} near the entrance to the precipitation pond.

The lower seepage ditch was not monitored as often as the upper ditch. Nevertheless, pHs at seepages ranged from 5.6 to 3.6. Ehs ranged from 272 to 320 mV (TABLE 5). The main stream of the lower ditch had pHs which ranged between 5.0 and 3.16. Ehs ranged from 315 to 461 mV. Conductivities varied between 590 and 1300 μmhos cm^{-1} (TABLE 5). On the June trip, oxygen concentrations in the seepage water were determined. These ranged from a low of 2.5 mg L^{-1} at the 106 m seep, to 10 mg L^{-1} (TABLE 5). Flow rates, measured in June, were 113 cm^3 s^{-1}.

Nutrients were measured in upper seepage water on several occasions. Ammonium tests were performed on the first trip, and values of 0.7 mg L^{-1} NH3-N were found. Subsequent use of the Nesslers Reagent produced a precipitate due to the high iron content, rendering the data obtained inaccurate. The nitrate/nitrite test produced no color, indicative of below detection limit nitrate concentrations. However, addition of a known concentration of nitrite to the water, did not produce the desired color, suggesting that the cadmium reduction method of nitrate determination may also have had interferences. The phosphate test, however, seemed to work satisfactorily.

Readings with the phosphate test are shown in TABLE 6. Concentrations in excess of 2.4 mg L^{-1} were determined in the A11 seep, and ranged from a low of 1.3 to a high of 5.5 mg L^{-1} at different positions and times in the upper ditch (TABLE 6). Measurements made on June 15 indicated that freshly collected seepage water had a PO_4-P concentration of 5 mg L^{-1}, measurements at short distances from the seep, however, were considerably lower (1.2

m - 1.3 mg L^{-1} and 4.2 m - detection limit; TABLE 6). Measurements of seepage water taken several hours after collection were also considerably lower (detection limit). Measurements of P from ICP data, were at or below detection limits of 1 mg L^{-1} (APPENDIX 1).

Ferric iron concentrations were measured on the June trip. These results indicate that the oxidized form of iron ranged between detection limit and 1 mg L^{-1} for the first 20 m of the ditch, rising to 4 mg L^{-1} at the weir.

Chlorides were also measured on the first June trip. Chloride concentrations ranged from 41 to 70 mg L^{-1} in the upper seepage ditch.

3.2 Water Chemistry

The major metal ions in the A11 seep water as determined by ICP were iron and sulphur, with concentrations in excess of 100 mg L^{-1} (FIGURE 1). The next most abundant elements were aluminum and manganese, which ranged from about 20 to 90 mg L^{-1}. The seepage water characteristics changed slightly with time, suggesting dilution with ground water.

Data from 1991 ICP samples were arranged according to water flow path in FIGURES 2-6. In these figures, 0 represents the A11 seep, and distances downstream are represented by

their meter numbers. P1-6 are samples from peritraps. Lower ditch samples from m 42-127 represent meters from the riffle (MAP 2).

Iron ranged from 100 mg L^{-1} to 400 mg L^{-1} in the A11 seep, with a slightly decreasing trend thereafter (FIGURE 2), ranging from 400 to 200 mg L^{-1}. Iron concentrations in the lower seepage ditch were considerably lower. The highest concentration was present in the 90 m seep at 35 mg L^{-1}, dropping to less than 1 mg L^{-1} by 127 m.

Sulphur ranged from 320 mg L^{-1} to 1000 mg L^{-1} in the A11 seep, remaining relatively constant thereafter, with the exception of 15 m seepage water, which produced a range between 800 and 1100 mg L^{-1} (FIGURE 3). Sulphur concentrations in the lower seepage ditch were considerably lower. The highest concentration was present in the 90 m seep at 730 mg L^{-1}. Otherwise, the concentrations were relatively constant between 200 and 300 mg L^{-1}.

Aluminum ranged from 25 mg L^{-1} to 94 mg L^{-1} in the A11 seep depending on date of sampling, but remaining relatively constant for the first 14 m, between 80 and 90 mg L^{-1} (FIGURE 4). Thereafter, concentrations dropped to around 60 mg L^{-1}. Aluminum concentrations in the lower seepage ditch were considerably lower (12 mg L^{-1}), with the exception of the 90 m seep, at 95 mg L^{-1}.

Manganese ranged from 17 mg L^{-1} to 54 mg L^{-1} in the A11 seep. Concentrations ranged between 32 and 70 mg L^{-1} along the ditch (FIGURE 5). Manganese concentrations in the lower seepage ditch were similar. The highest concentration was present in the 90 m seep at 82 mg L^{-1}. Around that point, the concentrations ranged from 23 to 35 mg L^{-1}. Other elements were also present in the ditch waste water. ICP elemental analyses of these elements are listed in APPENDIX 1.

3.3 PPC Elemental Composition

Algae growing in the A11 seep were found together with metal precipitates. Because of the complexity of the interaction between algae and metal precipitates, both together are called Periphyton Precipitate Complexes (PPCs). Periphyton is a generic term for surface-bound communities of algae, fungi and mosses. Even though *Ulothrix* and *Temnogametum* dominated the algal community, other species were present (see Section 3.4).

The primary component of PPCs from the upper seep was iron. Iron concentrations in PPCs exceeded 20% of the dry weight of the PPC (FIGURES 6,7 upper curves). Sulphur concentrations were also quite high, a PPC measured in June contained 18% sulphur on a dry weight basis. Calcium and magnesium reached concentrations as high as 2-5 % of dry weight. In August, aluminum concentrations were also in excess of 1% of dry weight. The next most abundant element was phosphorus, which reached 0.1-0.4% of dry weight.

The elemental composition of upper and lower seepage ditch PPCs collected in June are compared in FIGURE 6, along with elemental composition of the water in which they were growing. The two prominent elements which are accumulated by both PPCs are iron and sulphur. Iron concentrations in upper seepage PPCs, however, were almost 10 x higher than those in lower seepage PPCs. Sulphur concentrations were 40 x higher in the upper seepage PPCs. Aluminum concentrations were similar in both ditch PPCs. Phosphorus concentrations were 3660 μg gdw^{-1} in the upper seepage PPCs, while only 1000 μg gdw^{-1} in the lower seepage PPCs. Manganese concentrations, however, were 24 x higher in lower seepage PPCs than in upper seepage PPCs.

PPCs from the upper seepage ditch at A11 were compared between June and August in FIGURE 7. June PPCs contained considerably more sulphur than August PPCs, whereas August PPCs had slightly more iron. Calcium, magnesium, sodium, aluminum, and manganese were considerably higher in August PPCs, while being almost identical in seepage water. Phosphorus, zinc and L.O.I. were higher in June PPCs, than in August PPCs.

3.4. Taxonomy and Distribution

Selminco Summit AMD seeps can be located by finding areas populated by the green filamentous algae *Ulothrix*, *Microspora*, *Temnogametum*, and the diatom *Eunotia*. Other drainage ditches around the dump contain *Ulothrix*, *Spirogyra*, and *Zygogonium*.

Algae grew at a number of the seeps along the upper ditch. Their distribution was localized in the immediate vicinity of several seeps as shown in PLATE 1. The algae belonged to the genera *Ulothrix* and *Temnogametum*, along with smaller numbers of the diatom *Eunotia*. Many of these algae are common to mining site seeps (Whitton 1970). Most of these algae were bright green, indicating that there was sufficient nitrogen and phosphorus for pigment protein production. Algae downstream from the seeps were progressively lighter in colour, suggesting that nitrogen and/or phosphorus may have been limiting to these algae.

In October, a survey mapped the location, areal extent and density of the algal populations in the upper seepage ditch, with respect to the seep at the permanent water sampling station, A11. The collection ditch with seeps and algal populations is shown in MAP 3.

Algal populations covered an extent of about 9.4 square meters of ditch with a calculated dry biomass of 1.6 kg. Major seeps with algae were found at A11 (0 m), 4.2 m, 9.2 m, 12.4 m, 14.4 m, and 18.9 m.

Populations also decreased in density and size with increasing distances downstream from the seeps. The limit of distribution appeared to be near a pH of 3.3, although in October, most of the upper ditch water had pHs in excess of pH 3.6.

The lower seepage ditch contained a mixture of *Ulothrix* and *Microspora* populations with a few cells of *Eunotia*. These populations covered the ditch almost entirely, being evenly distributed along the ditch. For most of the summer, the algae in the lower ditch were black to brown in color, indicative of poor growing conditions. Algae growing in close proximity to the seeps, however, were bright green.

3.5 Algal Productivity

Algae from around the seep at 18.9 m were used to measure algal productivity. The initial pH of the water was 4.0. The net primary productivity (NPP) of the algae (as measured by the apparent light bottle oxygen change) was between 0.35 and 0.56 mg O_2 gdw^{-1} h^{-1} and the respiration rate (dark bottle change) varied between 0.02 and 0.24 mg O_2 gdw^{-1} h^{-1} (TABLE 7). Production of oxygen during photosynthesis was measured as the change in light/dark bottle oxygen concentrations. Since oxygen reacts with ferrous iron, some of the photosynthetically-generated oxygen production was used to oxidize ferrous iron. Thus, NPP rates are underestimates.

The photosynthetic rates of algae in the A11 collection ditch were compared to photosynthetic rates of algae growing in the lower seepage ditch which had pHs around 3.4. As shown in TABLE 7, the NPP was very high while the ratio of respiration to gross primary productivity was relatively low. Apparent photosynthetic rates of these algae, however, would also be enhanced by the lower concentration of iron in the water.

NPP declined with decreasing pH. The regression line produced from these data indicates that NPP should be 0 at pH 3.3. This is also the lowest pH measured in the presence of algae (FIGURE 8).

Carbon dioxide is also a required plant nutrient. Carbon dioxide is converted to organic carbon through the process of photosynthesis. At strongly acidic pHs, all of the inorganic carbon in water is present as dissolved carbon dioxide. The concentration of carbon dioxide in waters at this pH is equivalent to the concentration of carbon dioxide in air, assuming the water is well mixed. Diffusion of carbon dioxide into water becomes a limiting factor in algal photosynthesis.

With prolific algal populations at seeps, one of the components must be adequate carbon dioxide. To test this, a plastic bag outside a metal frame was placed over the A11 seep. Over a 2 hour period, any escaping gas was collected in the bag over a 2 hour period. The presence of elevated carbon dioxide in the bag was confirmed using a Dräger gas detection system. While elevated carbon dioxide will enhance photosynthetic rates of algae in the seeps, that carbon is quickly bubbled off at low pHs.

3.6 Carbohydrates

Dissolved carbohydrates in the seepage ditches were measured in August under sunny skies. Data are shown in TABLE 8. Upper seepage ditch did not contain any appreciable quantity

of dissolved carbohydrates, in contrast to the lower seepage ditch which contained at least 0.1 g of glucose equivalents in each litre.

3.7 Transplant Studies

3.7.1. Experiment 1

Transplantation of seepage algae to the first precipitation pond in 1990 did not result in population establishment. No evidence of the algae was found two months later.

3.7.2 Peritraps - Experiment 2

After the lack of establishment was noted, the next step involved setting up small experimental enclosures in which water quality could be altered. Six peritraps were set up and filled with amendments, fertilizers and algae in early June. After two weeks, all peritrap surfaces were entirely coated with iron precipitate. No algae were found in the traps. However, some of the traps showed improved water quality, presumably due to treatment. The pH in all traps except the control was elevated (outside pH 2.9), some above 3.5 (traps 2 & 3). Traps 1 and 6 had pHs over 3.4. Traps 1 and 2 had the lowest acidities, which may be the result of dissolution of the limestone. Those which contained slow-release nutrients had acidities around 1250 mg L^{-1} $CaCO_3$ equivalents. The control contained water at pH

3.28, with a conductivity of 2950 μmhos cm^{-1}, and an acidity of 1230 mg L^{-1} $CaCO_3$ equivalents.

All traps which contained slow-release fertilizer showed elevated nutrient levels, as determined by Hach tests for phosphate. Trap 1 contained over 16 mg L^{-1} PO_4-P. Traps 5 and 6 also contained dissolved phosphate, in concentrations in excess of 16 mg L^{-1} PO_4-P. Further indication of nutrient presence was the abnormally high conductivity in trap 6 (6,000 vs. 3000 μmhos cm^{-1}), which contained 1 kg of slow-release NPK fertilizer.

3.7.3 Peritraps - Experiment 3

Between initiation on June 15, and the next visit on July 8, the traps were vandalized, destroying the netting structures and ripping the bags. No algae were found.

3.7.4. Peritraps - Experiment 4

After the vandalization, 2 of the traps were refitted as limnocorrals, i.e. raising the bag rim to the surface so that the entire volume of the bag was isolated from the bulk flow. The amendments and fertilizers were modified. More algae were added to the limnocorrals. During the August field trip, the limnocorrals were found still intact, but all of the algae in the limnocorrals were dead.

3.7.5. Peritraps - Experiment 5

A third trap was converted to limnocorral, and the amendments and fertilizers modified again. The major difference in this run was that the pH of the isolated bag water was, in each case, brought up above pH 3.5 with sodium bicarbonate. Ten grams fresh weight of algae were inoculated into each limnocorral.

The limnocorrals were still intact in mid October. However, all limnocorrals contained a fine layer of silty mud in the bottom of the bags, covering fertilizer, hay, and sodium bicarbonate. Limnocorral 4 (with sodium bicarbonate) still contained green algae, and pHs in the mud at the bottom gave readings of 3.85. Limnocorral 5 (hay and alfalfa) contained no algae. The pH of the mud was 2.99. Limnocorral 6 (hay and NPK sausage) contained some live algae, and the pH of the mud at the bottom was 4.96. The outside pH was 3.25.

4.0 CONCLUSIONS

Evidence from these seepage studies suggests that algae are growing in the Selminco upper seepage areas because they are provided with a) pHs above 3.3, a source of dissolved nutrients, and possibly elevated carbon dioxide concentrations. Thus, algal distribution may be limited by lack of phosphate (and nitrogen?), lack of inorganic carbon, and acidic pHs. Data from the limnocorrals indicate that raising pH above 3.5, providing carbon dioxide (and

carbonate buffering capacity) and increasing nutrients enables algae to survive in the precipitation pond.

Algal distributions in the lower seepage, exist in low pHs, high acidities, and high aluminum concentrations. The lower seepage ditch seeps contain considerably less iron than upper seepage water. Ehs are somewhat higher, as is oxygen content of the water. This indicates that the water seeping into the lower ditch may already be oxidized. Thus, the greatest difference between upper and lower seepage streams was in the iron content, and the oxidation state of the water.

Algal distributions may be explained more simply. The oxidation and hydrolysis of iron in the upper seepage ditch increases acidity, lowers pH, and removes phosphorus. Thus all of the above characteristics, any one of which could limit algal distribution, are the result of iron oxidation. Most or all of the oxidation of ferrous iron has already occurred by the time water seeps into the lower ditch.

The pH of A11 seepage water is controlled by the oxidation of ferrous iron to ferric iron. Oxidation of the upper seepage water is confirmed by the rising Ehs and increased oxygen content of mainstream upper ditch water away from the seeps. Increased oxygen content of surface water allows the oxidation and hydrolysis of ferrous iron, increasing acidity, and lowering pH. At pHs below 4, inorganic carbon cannot remain in solution, in concentrations

in excess of that in air. Any excess carbon dioxide concentration in seep water will quickly be lost to the atmosphere.

As iron precipitates in the upper ditch and ponds, it forms a crust-like covering on any submerged surface, including algae. The primary function of the precipitation pond was to restrict the distribution of precipitate. If the carbon amendment in the ARUM pond is coated with iron it cannot provide the necessary conditions for alkalinity-generation. Algae that are coated with precipitate, become "fossilized".

Algae growing in the upper seep are found together with metal precipitates. Those algae in the upper seep, where iron precipitation dominates, are found with a corresponding high iron content. The complexes, termed Periphyton Precipitate Complexes or (PPCs) in the upper seepage are complexed with metal precipitates which comprise about 83% of the complex, in contrast to PPCs from the lower seepage ditch which are only 39% precipitate. The major constituent of the precipitate fraction of the upper seepage PPCs is iron, which comprises 26% of the dry weight of the PPC. Those PPCs in the lower seepage contain only 1.7% iron on a dry weight basis. Aluminum appears to be co-precipitated with the iron, as it reaches an average of 1% of the dry weight of upper seepage PPCs, while only 0.2% of the lower seepage PPCs.

Photosynthetic rates of algae in Selminco seepage water differed in water from different locations. The simplest description of the water used pH, and photosynthetic rates appeared

to be negatively related to pH. However, since pH is also a good indicator of oxidation state in a ferrous/ferric dominated system, photosynthetic rates could equally have been negatively related to the oxidation state of iron. Photosynthetic rates in upper seepage water were low compared to rates in lower seepage water, where oxidation of water was high, but iron concentrations low. Ferrous iron may also have competed for oxygen produced by photosynthesis, lowering estimates.

The measured carbohydrate concentrations in both seepages were related to three factors. First, given the same nutrient concentrations, the significantly lower photosynthetic rate of upper seepage algae will produce less dissolved carbon than lower seep algae. Secondly, the density of algae in the upper seepage ditch was considerably lower than found in the lower ditch. Thirdly, the flow of water in both ditches was also different. The upper seepage ditch flow rates were a minimum of ten times higher than lower seepage flows.

In the seeps, where pH, carbon dioxide, and nutrient levels are satisfactory for growth, algal populations flourish. Oxygen released during photosynthesis, raises the redox potential, and precipitates iron, phosphate, and possibly aluminum. The rate at which water flows from the seeps, and the rate of photosynthesis, regulate the rate at which precipitate is formed. Under some circumstances, the precipitates can build up faster than algal growth. In this case, the algae fossilize themselves in iron precipitate. Live algae found in seeps with 30% iron were not uncommon.

5.0 LITERATURE

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FIG. 1: All SEEPAGE WATER
Elemental Composition

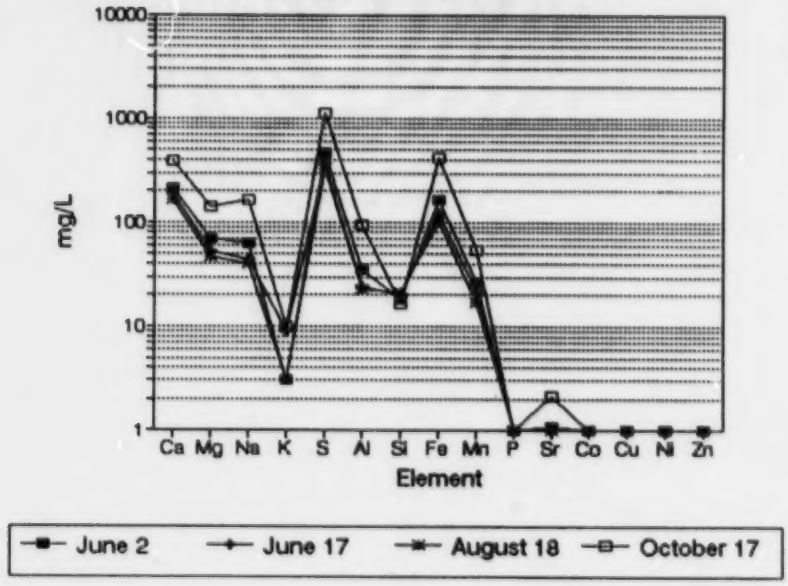


FIG. 2: IRON DISTRIBUTIONS
Upper/Lower Ditches

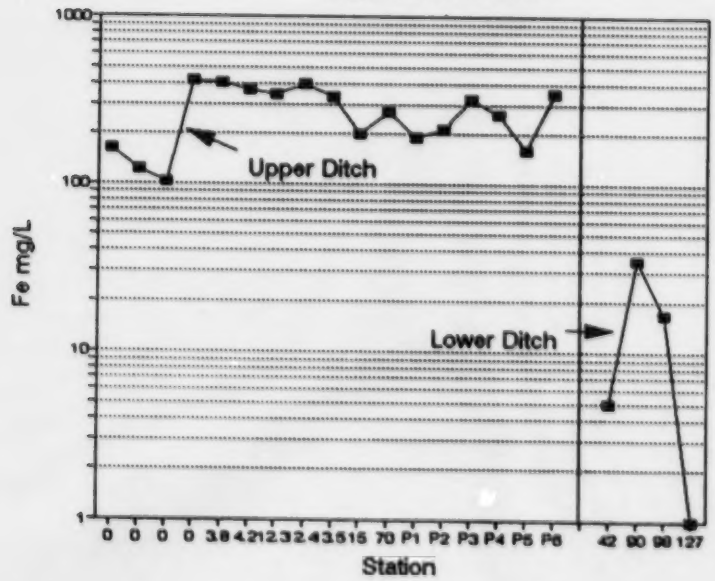


FIG. 3: SULPHUR DISTRIBUTIONS
Upper/Lower Ditches

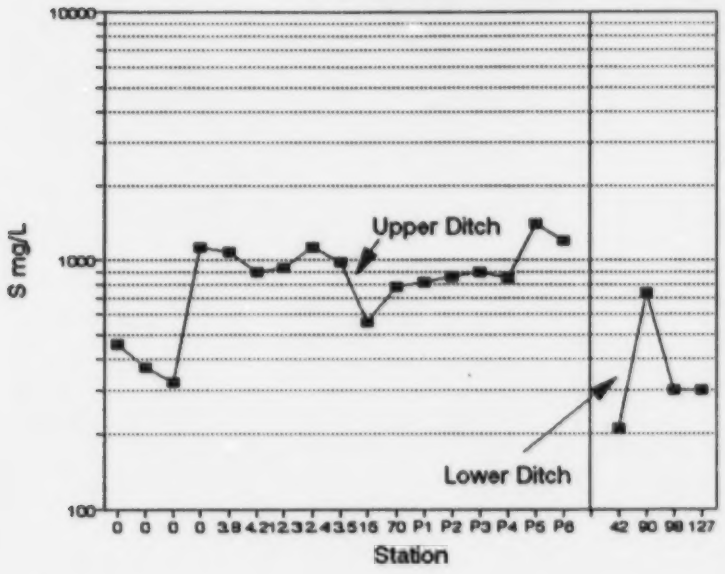


FIG. 4: ALUMINUM DISTRIBUTIONS
Upper/Lower Ditches

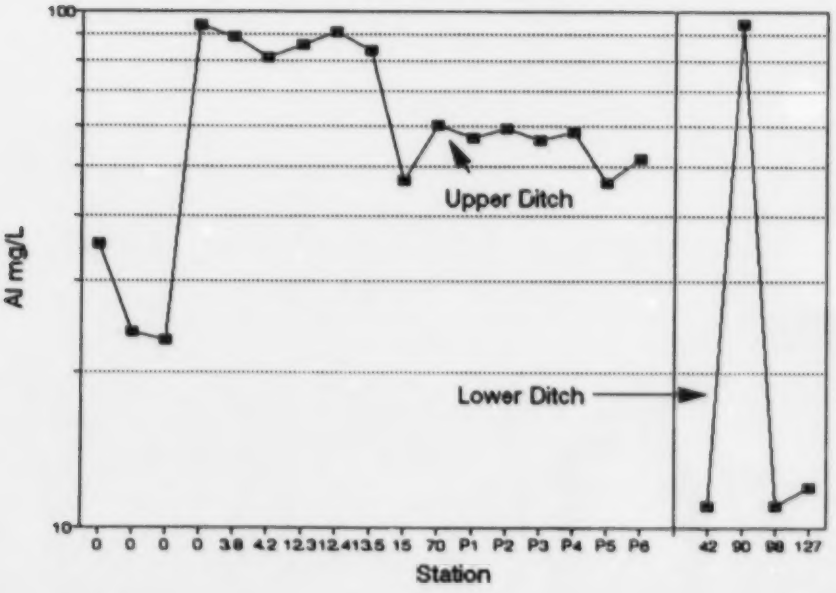


FIG. 5: MANGANESE DISTRIBUTIONS
Upper/Lower Ditches

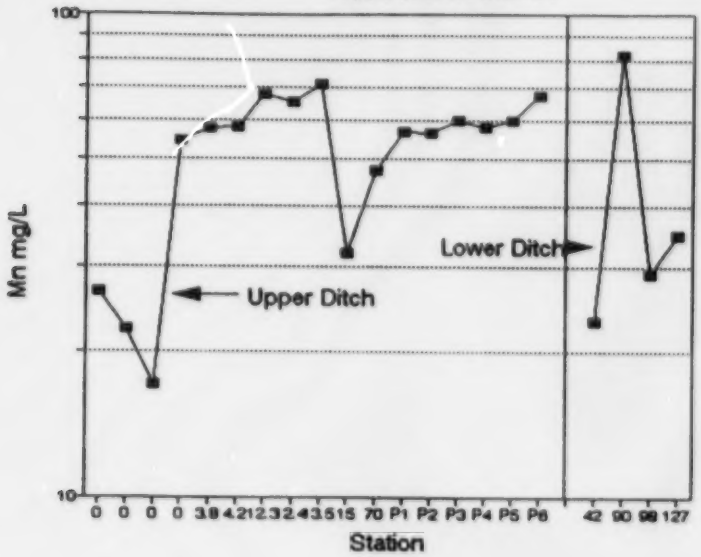


FIG. 6: A11 - ELEMENTAL COMPOSITION
Lower and Seepage PPCs and Water

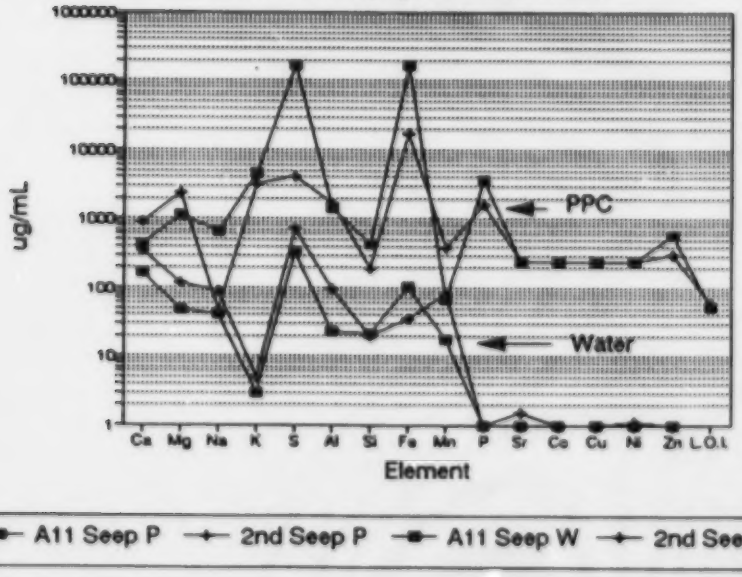


FIG. 7: A11 - ELEMENTAL COMPOSITION
Seepage PPCs and Water

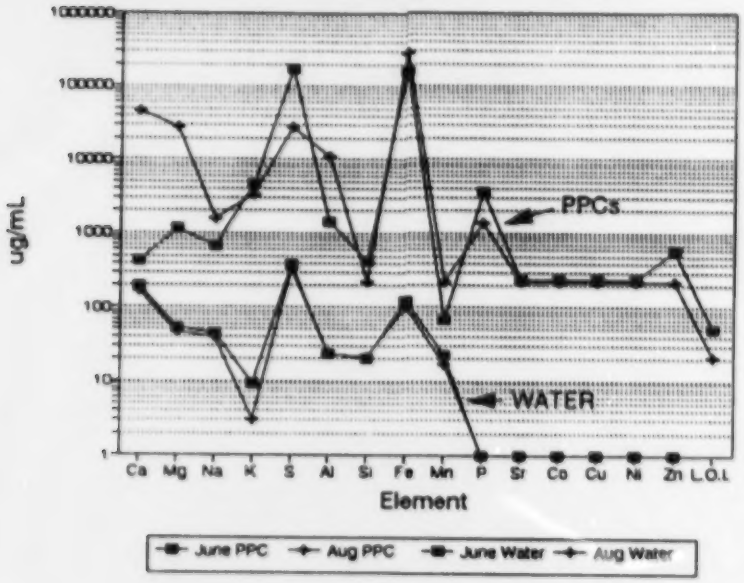


FIG. 8: pH vs. NET PRIMARY PRODUCTIVITY
A11 Seepage Ditch PPCs

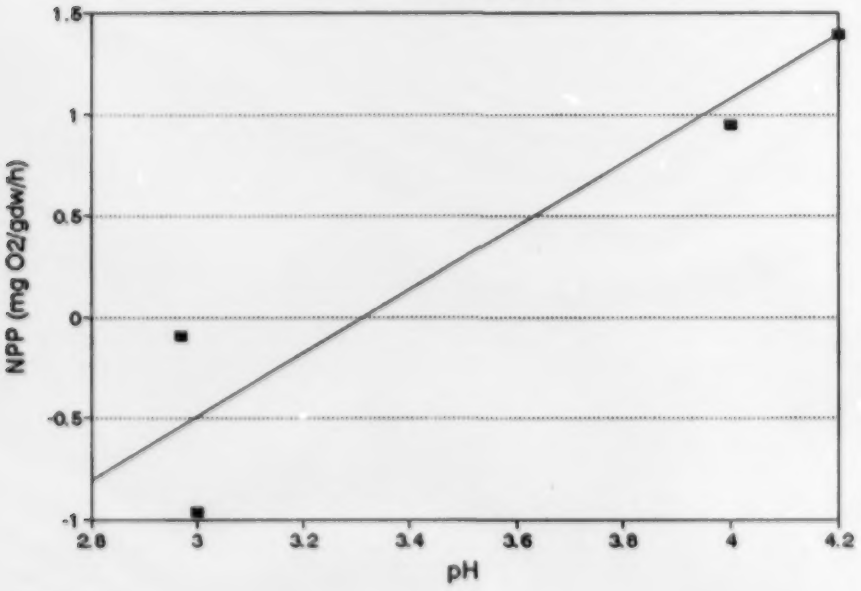


TABLE 1: SEEP WATER FIELD DATA

DATE	pH	Cond. umhos/cm	Eh mV	Acidity mg/L
Upper Seep - A11				
June 2	3.99	590	315	700
June 17	4.46	1400	196	460
August 18	4.08	1888	120	455
October 17	4.21	2070	201	nd
Lower Seep - 97 m				
June 17	3.92	2400	253	910

nd = not determined

TABLE 2: UPPER COLLECTION DITCH SURVEY, JUNE 1, 1991

SEEPS						MAIN FLOW				
DISTANCE m from A11	pH	Condo umhos/cm	Eh mV	Oxygen mg/L	Temp C	pH	Condo umhos/cm	Eh mV	Oxygen mg/L	Temp C
0	3.9	nd	227	1.2	7.8	3.6	nd	294	6	13.7
1.3	nd	nd	nd	nd	nd	3.9	nd	244	3.7	8.6
16	nd	nd	nd	nd	nd	3.8	nd	260	3.5	11.2
18.4	nd	nd	nd	nd	nd	3.8	nd	274	3.9	9.6
23	3.6	nd	267	nd	7.9	nd	nd	nd	0.8	nd
35	nd	nd	nd	nd	nd	3.5	nd	285	7.7	16.1
42	nd	nd	nd	nd	nd	3.5	nd	295	8	15.9
UPPER DITCH SURVEY, JUNE 15, 1991										
0	4.5	1400	196		15.0	nd	nd	nd		nd
4.2	3.7	1455	359		13.2	nd	nd	nd		nd
15.1	4.1	1432	307		13.7	nd	nd	nd		nd
16	nd	nd	nd		nd	3.3	1951	390		22.3
33	nd	nd	nd		nd	3.3	3290	378		21.8
42	nd	nd	nd		nd	3.6	3450	339		17.2

nd = not determined

TABLE 3: UPPER COLLECTION DITCH SURVEY, AUGUST 1991

SEEPS					MAIN FLOW			
DISTANCE	pH	Condo	Eh	Temp	pH	Condo	Eh	Temp
m from A11		umhos/cm	mV	C		umhos/cm	mV	C
0	4.1	1880	120	12.2	4.0	1870	261	12.5
1.4	4.0	2230	192	13.1	3.8	1750	342	15.9
4.2	4.1	2280	251	12.5	3.8	1880	305	15.0
4.9	3.9	2860	242	12.2	nd	nd	nd	nd
6.4	4.1	2870	230	13.1	3.8	2410	327	16.0
11.6	4.2	3220	243	12.1	3.9	2210	321	16.8
12.4	4.2	3650	238	12.1	3.8	2760	316	15.6
13.8	4.0	4010	264	11.6	3.7	2630	318	17.1
14.3	nd	nd	nd	nd	3.4	4180	259	11.6
15.1	3.4	4390	179	11.3	nd	nd	nd	nd
18.9	3.3	nd	248	11.4	nd	nd	nd	nd
21	nd	nd	n.d.	nd	3.4	nd	311	22.6
24	nd	nd	n.d.	nd	3.4	nd	321	22.2
30	nd	nd	n.d.	nd	3.4	nd	319	21.8

nd = not determined

TABLE 4: UPPER COLLECTION DITCH SURVEY, OCTOBER 1991

SEEPS					MAIN FLOW			
DISTANCE	pH	Condo	Eh	Temp	pH	Condo	Eh	Temp
m from A11		umhos/cm	mV	C		umhos/c	mV	C
0	4.2	1770	164	9.2	3.8	1830	304	9.5
1.4	4.1	ts	187	ts	3.9	2130	288	10.0
4.2	3.9	2520	210	10.0	3.8	2170	292	9.9
4.9	nd	nd	nd	nd	nd	nd	nd	nd
6.4	4.0	ts	191	ts	3.7	1970	292	10.0
11.6	4.4	1230	179	10.0	nd	nd	nd	nd
12.4	3.8	1180	195	10.0	3.6	2010	346	10.0
13.8	3.7	1100	194	10.1	3.7	2440	310	10.3
14.3	nd	nd	nd	nd	nd	nd	nd	nd
15.1	3.8	ts	201	ts	3.8	2650	318	10.3
18.4	3.7	1970	224	10.1	3.7	2520	284	10.3
21	3.5	2180	224	10.0	3.6	2100	299	10.2
24	nd	nd	nd	nd	3.6	2150	298	10.1
30	nd	nd	nd	nd	3.6	2180	313	9.9

nd = not determined

ts = too shallow for determination

TABLE 5: WATER CHEMISTRY FROM LOWER SEEPAGE

June 1	Seepages					Ditch Centre				
m from riffle	pH	Condo	Oxygen	Eh	T	pH	Condo	Oxygen	Eh	T
1	5.57	nd	7.7	272	13.7					
12.5	4.17	nd	10.2	317	17.2	4.95	nd	10.8	315	19.3
106	3.62	nd	2.5	320	8.9	3.41	nd	8.8	405	12.7
195						3.54	nd	10	413	14.3
June 15										
90	3.92	2400	nd	253	17					
October 15										
27						3.34	590	nd	400	13.8
42						3.25	1020	nd	461	13
58						3.16	1250	nd	443	15
73						4.16	1050	nd	389	17
98						4.5	1130	nd	343	17
108						4.32	1180	nd	326	18
117						4.16	1280	nd	356	18
127						4.06	1300	nd	355	18

TABLE 6: SEEPAGE DITCH NUTRIENTS

June 1	PO4-P	NO3-N	NH4-N	Acidity	Cl
A11	2.4	dl	1	700	70
18.4	5	dl	0.7	1400	dl
Weir	5.5	dl	0.65	1100	70
June 15					
A11	5	nw	nw	460	
1.2	1.3	nw	nw		
Centre 1.0	2.9	nw	nw		
Centre 2.5	0.8	nw	nw		
4.2	dl				
August 16					
A11	dl	nw	nw	455	41
6.4	dl	nw	nw	780	
12.4	dl	nw	nw	1160	
15.1	dl	nw	nw		
weir	dl	nw	nw	1250	51
October 16					
A11	0.5	nw	nw		
1.3	0.2	nw	nw		
4.2	0.5	nw	nw		
Centre 4.2	0.2	nw	nw		
12.4	0.7	nw	nw		
18.4	0.5	nw	nw		
weir	dl	nw	nw		

nw = not working
dl = = detection limit

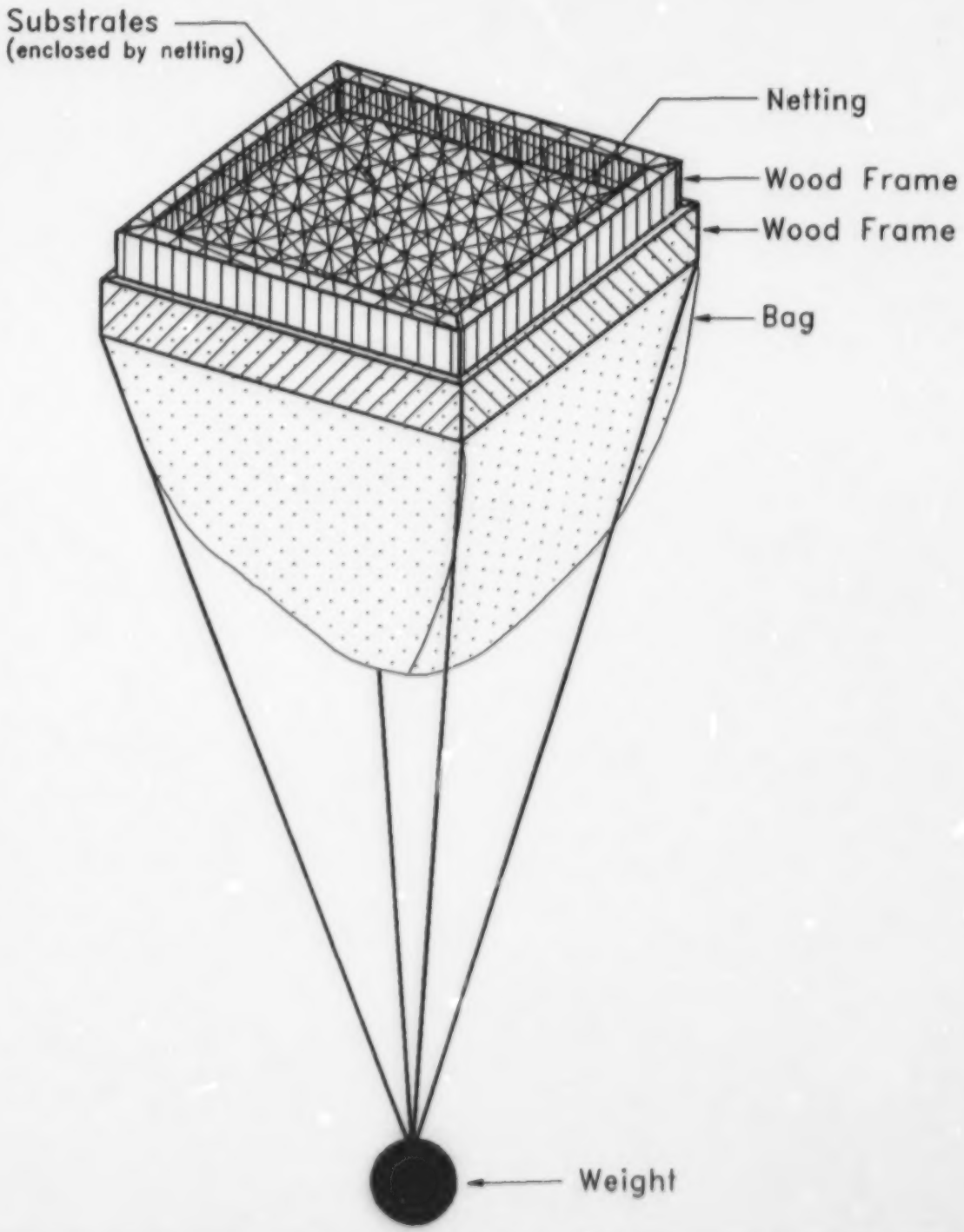
TABLE 7: PRIMARY PRODUCTIVITY OF DITCH PPCs

Time	NPP	R	T
	mgO2/gdw/h	mgO2/gdw/h	deg C
A11 Seepage Collection Ditch			
09:30-11:30	0.43	0.24	14.5
12:00-14:00	0.55	0.08	17.0
14:30-16:00	0.35	0.02	19.0
16:30-18:00	0.56	0.03	17.0
Lower Seepage Collection Ditch			
09:45-12:00	3.17	0.60	19.5
12:30-15:00	1.44	0.33	17.0

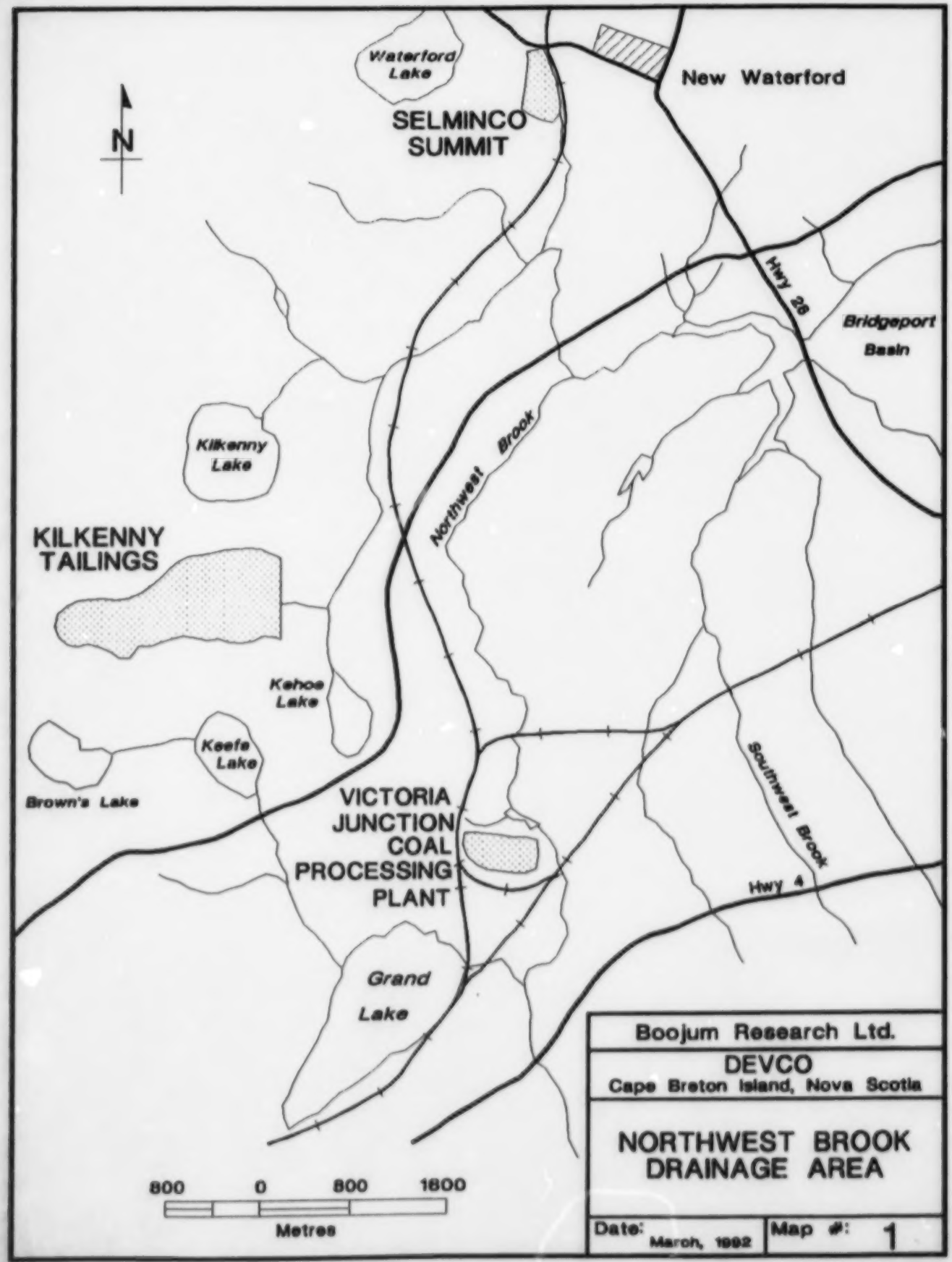
TABLE 8: DISSOLVED CARBOHYDRATES IN SEEPAGE DITCH WATER IN AUGUST

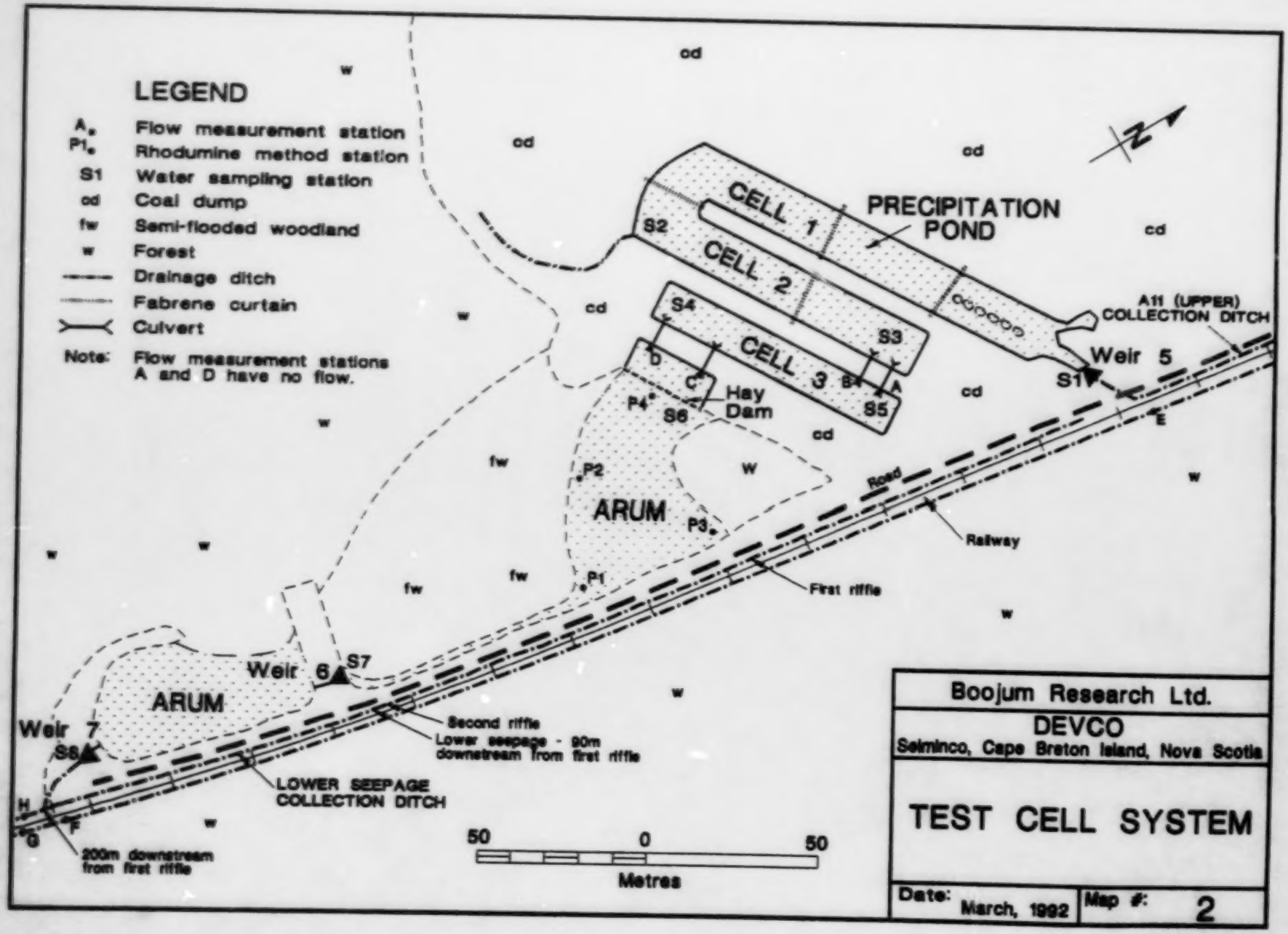
SITE/TIME	g/L (glucose)
Upper Seepage Ditch	
10:00	<0.01
12:00	<0.01
14:30	<0.01
Lower Seepage Ditch	
09:45	>0.1
13:20	0.1

SCHEMATIC OF PERITRAP



SCHEMATIC 1


Waterford Lake
New Waterford
SELMINCO SUMMIT
N
Hwy 28
Bridgeport Basin
Kilkenny Lake
Northwest Brook
KILKENNY TAILINGS
Kehoe Lake
Keefe Lake
Brown's Lake
VICTORIA JUNCTION COAL PROCESSING PLANT
Southwest Brook
Hwy 4
Grand Lake
800 0 800 1600
Metres
Boojum Research Ltd.
DEVCO
Cape Breton Island, Nova Scotia
NORTHWEST BROOK DRAINAGE AREA
Date: March, 1992
Map #: 1


LEGEND
A Flow measurement station
P1 Rhodumine method station
S1 Water sampling station
cd Coal dump
fw Semi-flooded woodland
w Forest
Drainage ditch
Fabrene curtain
Culvert
Note: Flow measurement stations A and D have no flow.
CELL 1
CELL 2
CELL 3
PRECIPITATION POND
S2
S3
S4
S5
S6
S7
S8
S1
A
B
C
D
E
F
G
H
Weir 5
Weir 6
Weir 7
A11 (UPPER) COLLECTION DITCH
Hay Dam
ARUM
ARUM
P1
P2
P3
P4
Road
Railway
First riffle
Second riffle
Lower seepage - 90m downstream from first riffle
LOWER SEEPAGE COLLECTION DITCH
200m downstream from first riffle
50 0 50
Metres
Boojum Research Ltd.
DEVCO
Selminco, Cape Breton Island, Nova Scotia
TEST CELL SYSTEM
Date: March, 1992
Map #: 2

Boojum Research Ltd.

DEVCO

Selminco Summit, Cape Breton Island, Nova Scotia

A11 SEEPAGE DITCH

Date: March, 1992

Map #: 3

LEGEND

- Seepage location
- Algae bloom
- Dead algae
- Sedges
- Osmocote sausage
- Riffles
- Railway
- Road
- Weir #5
- Ditch
  direction of slope

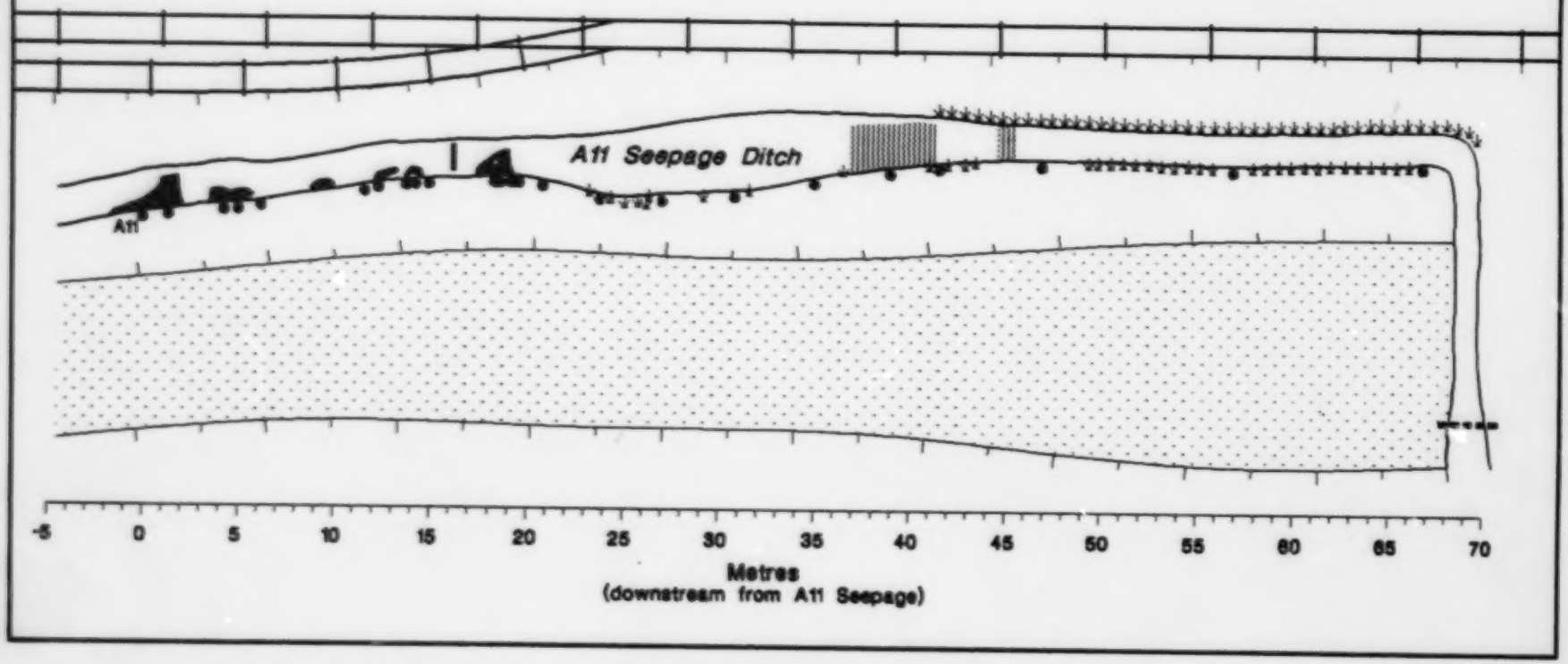


PLATE 1: *Ulothrix-Temnogametum*-PPCs at the A11 seep. Note the build up of iron hydroxide around the perimeter of the population.

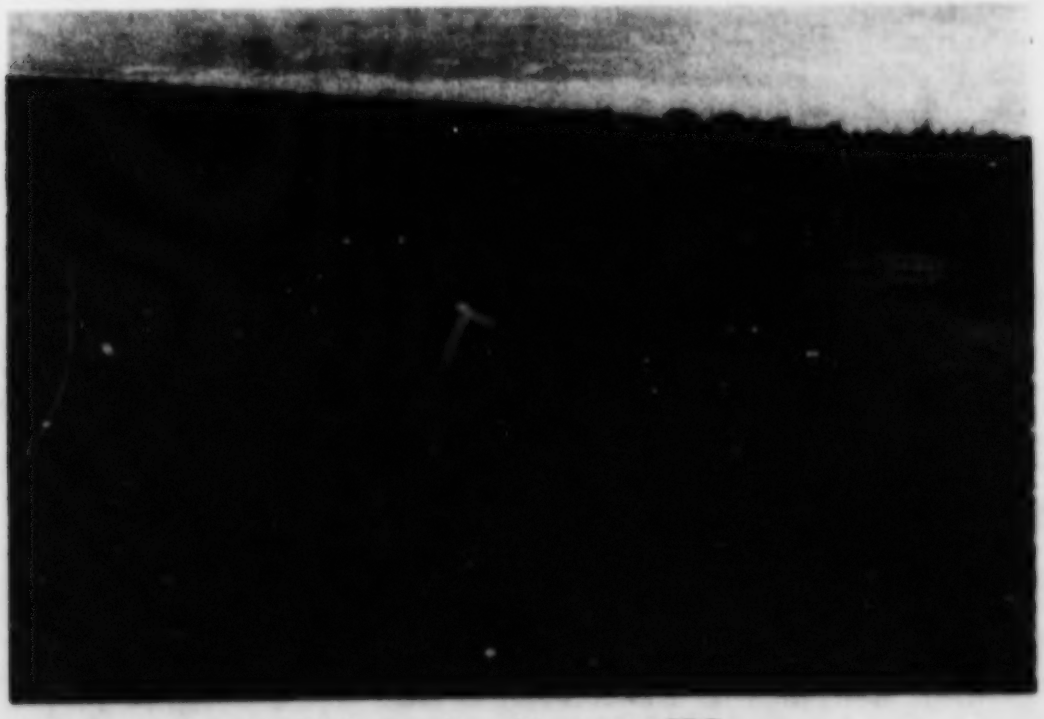


PLATE 2: A11 Seepage Ditch, overview with seepage PPCs.

APPENDIX

APPENDIX - Water and PPC Elemental Assays

SAMPLE DATE		2-Jun-91	17-Jun-9	18-Aug-9	17-Oct-9	17-Oct-9	18-Aug-9	18-Aug-9	17-Oct-9	2-Jun-91	18-Aug-9	2-Jun-9
SAMPLE VOLUME		100	100	100	100	100	100	100	100	100	100	100
ASSAYERS CODE		2779	2834	3172	3593	3594	3173	3174	3595	2780	3175	2781
SAMPLING LOCATIO		SELMIN	SELMIN	SELMIN	SELMIN	SELMIN	SELMIN	SELMIN	SELMIN	SELMIN	SELMIN	SELMIN
		0	0	0	0	3.8	4.2	12.3	12.4	13.5	15	70
		Seep	Seep	Seep	Stream	below	4.2 m	12.3 m	12.4 m	13.5 m	15 m	entry
Processing code		A11 FA	A11 FA	A11 FA	A11 FA	A11 FA	from A11 FA	from A11 FA	from A11 FA	from All FA	from A11 FA	W5 FA
ELEMENTS	Ag	0.005	0.005	1	0.005	0.005	1	1	0.005	0.013	1	0.005
	Al	35.5	23.9	23	94	89.1	81	86	91.2	83.8	47	60.2
	As	0.03	0.03	1	0.03	0.03	1	1	0.03	0.03	1	0.03
	B	0.02	0.02	1	0.03	0.03	1	1	0.02	0.02	1	0.02
	Ba	0.04	0.01	1	0.02	0.02	1	1	0.02	0.02	1	0.02
	Be	0.02	0.01	1	0.02	0.03	1	1	0.03	0.04	1	0.03
	Bi	0.03	0.06	1	0.05	0.05	1	1	0.05	0.03	1	0.03
	Ca	212	193	164	385	393	383	387	404	403	259	336
	Cd	0.01	0.01	1	0.02	0.03	1	1	0.02	0.01	1	0.01
	Ce	0.03	0.03	1	0.14	0.1	1	1	0.1	0.12	1	0.09
	Co	0.21	0.17	1	0.31	0.38	1	1	0.52	0.79	1	0.44
	Cr	0.01	0.01	1	0.01	0.01	1	1	0.01	0.01	1	0.01
	Cu	0.01	0.01	1	0.01	0.01	1	1	0.01	0.01	1	0.01
	Fe	165	122	102	418	402	368	342	394	335	202	270
	K	3	9	3	10	12	3	3	10	3	3	3
	La	0.01	0.01	1	0.04	0.03	1	1	0.04	0.01	1	0.01
	Mg	70.3	53	47	142	142	136	148	152	164	83	119
	Mn	26.5	22.2	17	54.4	57.8	58	68	65.4	71.5	32	47.1
	Mo	0.01	0.01	1	0.01	0.01	1	1	0.01	0.01	1	0.01
	Na	63	43.9	40	166	158	132	106	140	110	68	112
	Nb	0.01	0.01	1	0.01	0.01	1	1	0.01	0.01	1	0.01
	Ni	0.51	0.39	1	0.73	0.85	1	1	1.1	1.53	1	0.88
	P	0.2	0.2	1	0.2	0.1	1	1	0.1	0.1	1	0.1
	Pb	0.03	0.02	1	0.02	0.08	1	1	0.03	0.04	1	0.02
	S	459	370	322	1130	1080	891	929	1120	981	557	776
	Sb	0.05	0.05	1	0.05	0.05	1	1	0.05	0.05	1	0.05
	Se	0.1	0.1	1	0.1	0.1	1	1	0.1	0.1	1	0.1
	Si	18.6	20.1	21	16.5	16.7	18	20	17.4	19	20	17.3
	Sn	0.05	0.05	1	0.1	0.1	1	1	0.1	0.05	1	0.05
	Sr	1.08	0.84	1	2.16	2.14	2	2	2.16	2.06	1	1.67
	Te	0.1	0.1	1	0.1	0.1	1	1	0.1	0.1	1	0.1
	Th	0.01	0.01	1	0.02	0.01	1	1	0.01	0.01	1	0.01
	Ti	0.1	0.1	1	0.1	0.1	1	1	0.1	0.2	1	0.2
	U	0.5	0.5	1	5	5	1	1	5	0.5	1	0.5
	V	0.02	0.02	1	0.02	0.02	1	1	0.02	0.02	1	0.02
	W	0.1	0.1	1	0.1	0.1	1	1	0.1	0.1	1	0.1
	Y	0.06	0.04	1	0.15	0.15	1	1	0.17	0.2	1	0.13
	Zn	0.28	0.19	1	0.3	0.36	1	1	0.34	0.49	1	0.32
	Zr	0.01	0.01	1	0.01	0.01	1	1	0.01	0.01	1	0.01
L.O.I.												

SAMPLE DATE		17-Jun-9	17-Jun-9	17-Jun-9	17-Jun-9	17-Jun-9	17-Jun-9	18-Oct-9	18-Oct-9	18-Oct-9	16-Aug-9	16-Aug-
SAMPLE VOLUME		100	100	100	100	100	100	80	80	80	100	100
ASSAYERS CODE		2829	2830	2831	2832	2833	2835	3518	3520	3522	3166	3167
SAMPLING LOCATIO		SELMIN P2	SELMIN P3	SELMIN P4	SELMIN P5	SELMIN P6	SELMIN W2 Seep	SELMIN 10m bel. riffle	SELMIN 40m abo riffle	SELMIN 40 m bel. riffle	SELMIN A11 Seep	SELMIN S#6
Processing code		S1 FA	S1 FA	S1 FA	S1 FA	S1 FA	FA	FA	FA	FA	WA	WA
ELEMENTS	Ag	0.005	0.006	0.009	0.006	0.01	0.017	1	1	1	1	1
	Al	59.4	56.4	58.3	46.5	51.8	94.3	11	11	12	22	25
	As	0.03	0.03	0.03	0.18	0.03	0.03	1	1	1	1	1
	B	0.08	0.02	0.02	0.05	0.02	0.03	1	1	1	1	1
	Ba	0.02	0.02	0.02	0.02	0.01	0.04	1	1	1	1	1
	Be	0.02	0.03	0.02	0.01	0.02	0.02	1	1	1	1	1
	Bi	0.05	0.07	0.03	0.06	0.05	0.03	1	1	1	1	1
	Ca	311	413	389	429	565	347	215	177	225	177	270
	Cd	0.01	0.01	0.01	0.01	0.01	0.01	1	1	1	1	1
	Ce	0.08	0.08	0.1	0.08	0.12	0.39	1	1	1	1	1
	Co	0.41	0.57	0.53	0.51	0.59	0.76	1	1	1	1	1
	Cr	0.01	0.01	0.01	0.01	0.01	0.01	1	1	1	1	1
	Cu	0.02	0.01	0.01	0.01	0.01	0.02	1	1	1	1	1
	Fe	214	324	262	161	347	35.2	17	5	1	95	28
	K	6	5	5	954	287	5	5	6	4	4	9
	La	0.03	0.03	0.03	0.03	0.04	0.1	1	1	1	1	1
	Mg	120	133	125	127	147	118	55	40	59	48	101
	Mn	56.7	60	58.1	60	67.7	82.2	29	23	35	17	27
	Mo	0.01	0.01	0.01	0.01	0.01	0.01	1	1	1	1	1
	Na	105	109	102	124	124	90.7	52	34	52	44	39
	Nb	0.01	0.01	0.01	0.01	0.01	0.01	1	1	1	1	1
	Ni	0.79	1.01	1	0.97	1.12	1.1	1	1	1	1	1
	P	0.1	0.1	0.1	209	7.2	0.1	1	1	1	1	1
	Pb	0.02	0.02	0.02	0.02	0.02	0.02	1	1	1	1	1
	S	851	894	848	1410	1200	732	300	213	302	317	455
	Sb	0.07	0.06	0.05	0.05	0.07	0.05	1	1	1	1	1
	Se	0.1	0.1	0.1	0.1	0.1	0.1	2	2	2	1	1
	Si	16.8	19.6	19.7	21.9	19.2	20	6	6	7	21	9
	Sn	0.05	0.05	0.05	0.05	0.05	0.05	1	1	1	1	1
	Sr	1.67	1.97	1.81	2.1	2.69	1.54	2	2	2	1	1
	Te	0.1	0.1	0.1	0.1	0.1	0.1	1	1	1	1	1
	Th	0.01	0.01	0.01	0.01	0.01	0.01	1	1	1	1	1
	Ti	0.2	0.1	0.1	0.1	0.1	0.1	1	2	1	1	1
	U	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1
	V	0.02	0.02	0.02	0.02	0.02	0.02	1	1	1	1	1
	W	0.1	0.1	0.1	0.1	0.1	0.1	1	1	1	1	1
	Y	0.13	0.13	0.14	0.14	0.15	0.26	1	1	1	1	1
	Zn	0.65	0.34	0.31	0.35	0.52	0.93	5	1	1	1	1
	Zr	0.01	0.01	0.01	0.01	0.01	0.01	1	1	1	1	1
L.O.I.												

SAMPLE DATE		16-Aug-9	16-Aug-9	16-Aug-9	16-Aug-9	18-Jun-9	18-Jun-9	18-Aug-9	18-Aug-9	18-Aug-9	18-Aug-9
SAMPLE VOLUME		100	100	100	100						
ASSAYERS CODE		3169	3170	3171	3172	2661	2662	3472	3473	3474	3475
SAMPLING LOCATIO		SELMIN S#3	SELMIN Weir 5	SELMIN Fresh Water Ditch	SELMIN Rain Water	SELMIN Seep A11	SELMIN Seep Weir 2	SELMIN Seepdtc A11 Algae	SELMIN Seepdtc 4.2 m Algae	SELMIN Seepdtc 12.3 m Algae	SELMIN Seepdtc 15 m Algae
Processing code		WA	WA	WA	WA	AW	AW	AW	AW	AW	AW
ELEMENTS	Ag	1	1	1	1	2	2	226	226	234	230
	Al	27	57	1	5	1430	1660	11051	10860	13336	12431
	As	1	1	1	1	11	10	226	226	234	230
	B	1	1	1	1	24	22	226	226	234	230
	Ba	1	1	1	1	36	134	226	226	234	230
	Be	1	1	1	1						
	Bi	1	1	1	1						
	Ca	253	321	50	269	430	914	45783	34389	26907	18877
	Cd	1	1	1	1	2	2	226	226	234	230
	Ce	1	1	1	1	9	28	226	226	234	230
	Co	1	1	1	1	2	5	226	226	234	230
	Cr	1	1	1	1	24	9	226	226	234	230
	Cu	1	1	1	1	22	26	226	226	234	230
	Fe	53	219	1	1	184000	17000	284166	361991	209640	287753
	K	1	1	5	3	4520	3290	3383	3620	3276	3453
	La	1	1	1	1						
	Mg	93	112	2	129	1140	2370	27966	20814	16144	11971
	Mn	27	45	1	12	67	380	226	679	468	681
	Mo	1	1	1	1	2	2	226	226	234	230
	Na	45	97	21	6	686	47	1579	2262	1636	2993
	Nb	1	1	1	1						
	Ni	1	1	1	1	2	2	226	226	234	230
	P	1	2	1	1	3660	1600	1353	1131	936	1381
	Pb	1	1	1	1	28	21	226	226	234	230
	S	478	742	23	450	173000	4000	27966	50679	25269	39134
	Sb	1	1	1	1						
	Se	1	1	1	1	100	100	226	226	234	230
	Si	8	18	4	1	430	190	226	226	234	230
	Sn	1	1	1	1	10	10	226	226	234	230
	Sr	1	2	1	1	24	16	226	226	234	230
	Te	1	1	1	1						
	Th	1	1	1	1	2	2	226	226	234	230
	Ti	1	1	1	1						
	U	1	1	1	1	100	100	226	226	234	230
	V	1	1	1	1						
	W	1	1	1	1						
	Y	1	1	1	1						
	Zn	1	1	1	1	580	308	226	226	234	230
	Zr	1	1	1	1						
L.O.I.						52.8	60.1	20.9	26.8	30.6	27.3